U.S. DEPARTMENT OF COMMERCE
National Technical Information Service
PB80-109028

Air Pollution: Assessment Methodology and Modelling. Current Needs and Uses of Quality Models

NATO Committee on the Challenges of Modern Society, Brussels (Belgium)

May 79

PB80-109028

AIR POLLUTION

ASSESSMENT METHODOLOGY

and

MODELLING

Volume 101

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(Please read Instructions on the reverse before completing)

1. REPORT NO.	2.	3. RECIPIENT'S ACCESSION NO.
CCMS Report No. 101		PB 80 109028

4. TITLE AND SUBTITLE	5. REPORT DATE
Air Pollution, Assessment Methodology and Modelling	May 1979
	6. PERFORMING ORGANIZATION CODE
7. AUTHOR(S)	8. PERFORMING ORGANIZATION REPORT NO.
9. PERFORMING ORGANIZATION NAME AND ADDRESS	10. PROGRAM ELEMENT NO.
A report of the NATO/CCMS Pilot Study on Air Pollution Assessment Methodology and Modelling	11. CONTRACT/GRANT NO.
12. SPONSORING AGENCY NAME AND ADDRESS	13. TYPE OF REPORT AND PERIOD COVERED
North Atlantic Treaty Organization Committee on the Challenges of Modern Society	14. SPONSORING AGENCY CODE

15. SUPPLEMENTARY NOTES

16. ABSTRACT

This study describes the uses and needs for air quality models.

17. KEY WORDS AND DOCUMENT ANALYSIS

a. DESCRIPTORS	b. IDENTIFIERS/OPEN ENDED TERMS	c. COSATI Field/Group

18. DISTRIBUTION STATEMENT	19. SECURITY CLASS *(This Report)*	21. NO. OF PAGES
		68
	20. SECURITY CLASS *(This page)*	22. PRICE
		A04-A01

EPA Form 2220-1 (9-73)

USES AND NEEDS FOR AIR QUALITY MODELS

A Report of the NATO/CCMS Pilot Study on Air Pollution Assessment Methodology and Modeling

No. 101

COMMITTEE ON THE CHALLENGES OF MODERN SOCIETY
NORTH ATLANTIC TREATY ORGANIZATION
May 1979

Preface

The North Atlantic Treaty Organization (NATO) established the "Committee on the Challenges of Modern Society" (CCMS) at the November 1969 meeting of the North Atlantic Council.

The CCMS was charged with developing meaningful environmental and social programs that complement other international programs, and with showing leadership, first, in solution of existing problems and, second, in development of long-range goals for environmental protection in the NATO sphere of influence and in other countries as well. A first Pilot Study on Air Pollution was initiated by the CCMS at its inaugural meeting in December 1969. The United States (Environmental Protection Agency) has been the pilot nation with the Federal Republic of Germany (Federal Ministry of the Interior) and Turkey (Scientific and Technical Research Council) as copilot-nations.

The Pilot Study on Air Pollution was an action program designed to demonstrate and encourage the utilization of existing knowledge for the development of air quality management programs. It entailed the demonstration of a system approach to air quality management. Case studies have been carried out in Ankara, Turkey; Frankfurt, Federal Republic of Germany; St. Louis, U. S.; Oslo, Norway; South Holland Region, The Netherlands (NATO/CCMS Report No. 6, Appendices A - E).

The results of the pilot study are documented in NATO/CCMS Report No. 6 (Revised) "Guidelines to Assessment of Air Quality" of October 1972 and in NATO/CCMS Report No. 33 (Final Report) containing 15 recommendations as well as in several other documents, listed as Annex II to this document.

Starting from three of the above recommendations (VI, VII and XIV) the Federal Republic of Germany proposed to initiate a new Pilot Study on Air Pollution Assessment Methodology and Modeling at the CCMS Plenary Session on October 22 and 23, 1974.

These NATO/CCMS Recommendations are:

RECOMMENDATION VI

Member nations will co-operate to develop standardized methods for emissions data storage and retrieval to support requirements in the conduct of national air quality management programs. The US National Emission Data System (NEDS) might serve as a model for a common international system.

RECOMMENDATION VII

Member nations will co-operate to develop standardized techniques for projecting emissions and predicting future ambient air quality.

RECOMMENDATION XIV

Member nations agree the CCMS modeling activity has shown that there is a widespread need for further international co-operation to accomplish the following tasks:

Bring together model developers and air quality managers for exchange of ideas, discussion of users' needs and demonstration of modeling techniques.

Standardize modeling techniques for specific air quality management applications and consider how computerized models might be made available for all users.

Continue to review on-going air quality assessment studies.

In spring 1975 the North Atlantic Council approved the German proposal. The pilot study work started with the Federal Republic of Germany (Federal Ministry of the Interior) as pilot nation and the United States of America (Environmental Protection Agency) and Belgium (Service du Premier Ministre) as co-pilot nations:
A Working Group and two Panels were established with the following functions:

Assessment Methodology Panel

- Pursue and carry out Recommendations VI and VII
- Continue to review present and future assessment studies with respect to the application of assessment methodology.

Modeling Panel

- Develop standardized models for various air quality management applications.
- Develop programs to improve modeler/user communications in conjunction with the Assessment Methodology Panel and the Working Group.
- Continue as an information forum on new modeling concepts and techniques, organizing once a year international technical meetings on air pollution modleing and its application.

In addition the Working Group established an Ad-Hoc Group on Air Quality Management Systems to revise and update the NATO/CCMS Report No. 6 (Revised) 1972 by preparing a new document on "Guidelines to Air Quality Management Systems".

Another Ad-Hoc Group was set up for compiling a Glossary of Terms frequently used in assessment methodology, modeling and air quality management systems.

As an outcome of this Pilot Study on Air Pollution Assessment Methodology and Modeling the following NATO/CCMS documents are published (see also Annex III):

Air Quality Management System

- Guidelines to Air Quality Management System.

Assessment Methodology

- Air Pollution Emission Inventory Systems
- Air Pollution Emissions Projecting

Air Pollution Modeling

- Introduction to Air Quality Modeling
- Uses and Needs for Air Quality Modeling
- Bibliography on Grey Literature on Air Quality Modeling, Part I (Applied Models)
- Bibliography on Grey Literature on Air Quality Modeling, Part II (New Modeling Techniques)
- Practical Demonstration of Multiple Source Urban Air Quality Modeling (Gaussian Plume)
- Fundamentals for the Applications of a Gaussian Plume Model

Other Publications

- Glossary of Terms
- Proceedings of the 6th to 9th International Technical Meetings on Air Pollution Modeling and its Application
  (6th Meeting, 24. - 26. Sept. 1975, Frankfurt/Main, Germany)
  (7th Meeting, 7. - 10. Sept. 1976, Airlie House, USA)
  (8th Meeting, 20. - 23. Sept. 1977, Louvain-la-Neuve, Belgium)
  (9th Meeting, 29. - 31. Aug. 1978, Toronto, Canada).

The chairman of the Working Group wishes to acknowledge the scientists participating from pilot, copilot, and observer countries, and the many other persons, who assisted in the preparation of this document.

The panel, which performed diligently throughout the course of this effort, receives the highest praise. The panel members were:

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The addresses of the panel members are listed in Annex I.

Full recognition is given to each panel member for carrying out and coordinating review and other activities related to the development of this document in his respective country and to Ms. C. Morawa of the Federal Environmental Office, Germany for her effort in coordinating and organising and for editorial work.

For the Working Group,
Erich Weber, Chairman.

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1. INTRODUCTION

1.1 Historical Development of Model Use

A basic assumption in air quality management is that there are cause and effect relationships between pollutant emissions and ambient pollution concentrations. The fundamental physical principles governing such relationships have been under investigation for many years. The investigations have lead to mathematical methods for relating air pollution measured concentrations at a specific receptor to the rate of emission of pollutants from a variety of sources. Such mathematical methods have been called "air pollution dispersion models" or, more generally, "air quality simulation models".

Air quality management is inherently dependent on air quality models. Accepting this fact, several important questions must be addressed. How are the models used in the air quality management process? What is required in terms of model availability and accuracy? What is required for model inputs? Do existing models satisfy the requirements? These matters are the primary subjects of this report.

Members of academic research institutions in the NATO countries have actively worked with air quality simulation models for four decades. In the period from 1945 - 1965, the application of models (with a few notable exceptions) focused mainly on single sources. The models were used mostly to provide a basis for stack design and to analyze effects of field tests of weapons. The research and the pioneering applications gave rise in the latter portion of the 1945 - 1965 period to the development of multi-source dispersion models. These were used in urban situations to simulate sulfur dioxide and particulate matter pollution in several cities in the NATO community. They were integral factors in the air quality management procedures.

In the more recent past the need for models has increased dramatically. Public awareness of the need to conserve and protect air resources led to government air pollution control legislation and stringent control programs. Often the legislation and programs were based on the air quality management philosophy. In these cases, an urgent need for air quality models was generated. The needs stimulated the development of additional modeling approaches. Further, the need for models was broadened to include the simulation of photochemical pollution (smog), the distribution of secondary pollutants such as ozone, sulfates, nitrates and acid rain, and dispersion processes when influenced by complex terrain or sea and land breeze circulations.

At the same time, the number of political jurisdictions using traditional (primarily the Gaussian plume model) modeling procedures increased substantially. Experience with models, their requirements and their usefulness was acquired by a large number of people with a variety of technical backgrounds. Engineers, physicists, chemists, computer scientists and technicians applied the models as well as dispersion meteorologists. The range of applications broadened. The models were scrutinized from additional points of view.

Despite the rapid growth in model use and increased emphasis on model development, no single computational technique or standard method emerged as acceptable for all applications. Quite the opposite occurred. Because of differing conditions for application, availability of required input data, and desires for particular types of output information, the number of available models multiplied in nearly every NATO country. Occasionally the models differed substantially in basic assumptions and approach. More often, however, they differed only in

details as to the choice of parameters, the computational algorithms or the manner that the input and output data were handled. Generally the proliferation of models caused no difficulty for model developers, particularly since most models were based on the Gaussian assumption. However, the variety of models, whose most substantial differences may be in their names, has created practical and legal problems for users who are involved in the regulatory aspects of air quality management.

1.2 Air Quality Management

Ambient air quality standards form the basis of the air quality management control philosophy (de Nevers, et al., 1977). Other philosophies are best available emission control, standards, emission tax and cost benefit procedures. In practice, de Nevers, et al., observe that, present control programs tend to be a mixture of these "pure" philosophies with emphasis on air quality management or emission standards.

Whenever the control strategy involves air quality management, the control officials must manipulate the amount, location and time of emissions so that the air quality is in compliance with standards and so that it remains in compliance in the future. This may be a highly complex process. Precisely how models are used in the process varies considerably among political jurisdictions. The use of models depends on the regulatory approach, the acceptability of the models as a part of the regulatory process, the awareness of the model's utility, the availability of the appropriate models in user oriented packages, and the availability of the necessary resources to apply the models.

A significant constraint on the use of models is a reticence to base costly control decisions on results of analytical proce-

dures or models which contain assumptions that may not be unanimously accepted. It seems more scientific to await for exact facts before acting. But time does not stand still; to preserve air resources at times requires decisions that are guided by analyses which contain assumptions. This concern is often overcome in part by using monitoring data, considered by some more exact than modeling data, to complement the modeling results. Speaking to this matter, Slater (1974) emphasized that "both are necessary, but neither is sufficient by itself". The necessary monitoring facilities are rarely completely adequate. Models are required at the onset of an air quality management program to aid in ascertaining the nature and extent of the problems. Further, as Renson (1976) articulated very clearly, models can show gaps of knowledge. The results of models can force convergence of attention to the need to acquire particular data in adequate amounts and to pursue specific and most promising lines of inquiry.

1.3 Status of Models Used

The summary and conclusions of an OECD-report of 1970 were:

1. Existing air pollution prediction models are capable of providing useful estimates of urban air pollution levels and distributions. These models have applications in several general areas, including land use planning, evaluation of air pollution control strategies, short period (e.g. daily) predictions, and air quality monitoring.

2. Current models do not take into account transformation of pollutants, and the maximum geographic region which can be treated by the models is a few tens of kilometers in dimension. The greatest precision

results when concentration estimates are averaged over a long time and the whole region; for such cases an accuracy of ± 25 percent may usually be expected. Such precision is not possible in the case of short period, single point prediction, for which an order of magnitude error may occur. However, model estimates of single point concentrations likely to be exceeded only a few days each year can be expected to be accurate within a factor of two.

3. The prime requirement for the improvement of these models is a better understanding and representation of loss processes (deposition and washout) and transformation (chemical, photochemical and physical). Attempts to achieve more realistic estimates of plume characteristics from meteorological measurements should be regarded as of secondary importance, because there is no indication that more than marginal improvement will result. In general the undertaking of elaborations of existing models should be subject to the most critical scrutiny as regards the expected benefits.

4. In every case authorities initiating modelling programmes should seek the advice of a meteorologist experienced in this field, and should be prepared to support the effort required to ensure adequate operating experience. Furthermore agencies should make as much use as possible of the models in the establishment of comprehensive monitoring programmes.

This document may provide a useful historical record and be a guide for the development of air quality management methods.

2. USES OF AIR QUALITY SIMULATION MODELS IN THE NATO COUNTRIES

2.1 A Compendium of Model Uses

Table 1 is a compendium of model uses based on the 1976 survey by Dr. Rote. It is not professed to be all inclusive and comprehensive. The table is divided into several general categories of modeling activities that support air quality management functions. These activities include analyses to: (1) assess the cause of trends on air quality; (2) determine the nature of source contributions and meteorological factors in space, time and magnitude; (3) support effects/economics studies and the selection of air quality standards; and (4) make environmental impact assessments and evaluate the consequences of accidental releases of toxic substances. Most importantly, these and other model analyses are used to assist in developing policies and choosing strategies which will help to attain and maintain acceptable levels of air quality. Models are frequently used for these purposes in most countries even though specific air pollutant emission, ambient standards or other control philosophies have not been formally adopted. For many of the applications, both modeling and monitoring can play complementary rather than mutually exclusive roles.

Table 2 is a compilation of model uses for each country Dr. Rote visited. It provides another aspect of the extent of model application for the several purposes. This compilation is based on visits to specific institutions and is neither comprehensive nor exhaustive.

Table 3 lists references, mostly in English, which discuss model applications for purposes cited in Table 1. Dr. Rote observed that the vast majority of those who apply models

do not report their work in open literature. Some is reported in manuals, studies and other documents prepared by government agencies, intergovernment bodies and private concerns. (NATO/CCMS Document No. 70, "Bibliography of Grey Literature on Air Quality Modeling" contains examples). Consequently, the number of entries under each heading of Table 3 must not be interpreted as a measure of relative importance or the extent of each use.

The following sub-sections briefly discuss model applications and some of the specific user requirements for each of the applications listed in Tables 1, 2 and 3.

2.2 Historical Air Quality Trend Analysis

Consistent, long-term air quality monitoring can provide information concerning air quality trends over the years. However, the interpretation of the trend data is complicated by the redistribution of sources, changes in fuel characteristics or consumption, implementation of control programs and year-to-year variations in weather conditions. Several investigators have found that these factors can be separated by the judicious use of statistical analyses and long-term air quality models. Such separation can provide the basis for a "rational air quality management program" since an understanding of the causes of past trends can provide a foundation for projecting future air quality and the needed degree of control (Clarenburg, 1971).

Similarly, models have been used to eliminate weather factors from studies of changes in air quality during periods of extensive fuel shortages and fuel conversions (Siegel, 1975). Rudimentary models also have been used to normalize air pollution data for evaluating trends in air quality (U. S. EPA, 1973).

Table 1: Air Quality Model Applications

A. Historical Air Quality Trends Analysis

B. Characterization of Existing Air Quality in Multi-Source Areas
   1. Temporal and Spatial Air Quality Patterns
   2. Data Base Error Diagnosis
   3. Identification of Source Contributions
   4. Identification of Worst-Case

C. Stack Height Calculations

D. Support for Effects and Economic Studies

E. Selection of Air Quality Standards

F. Environmental Impact Statements

G. Attainment of Air Quality Standards
   1. Monitoring Network Design
   2. Formulation of Control Policies
   3. Licensing and Regulation
   4. Supplementing Control Systems
   5. Urban Alert Systems

H. Accidental Releases of Toxic Substances

Table 2: Model Applications in Various Countries

	Belgium	Canada	Denmark	Finland	France	Germany (FRG)	Italy	Netherlands	Norway	Sweden	U. K.	U. S.
A. Historical Air Quality Trends Analysis	x	x			x	x	x	x	x		x	x
B. Characterization of Existing Air Quality in Multi-Source Areas												
1. Temporal and Spatial Air Quality Patterns	x	x	x	x	x	x	x	x	x	x	x	x
2. Data Base Error Diagnosis			x	x	x	x	x		x	x		x
3. Identification of Source Contributions	x	x	x	x		x		x	x	x	x	x
4. Identification of Worst-Case	x	x			x	x	x	x	x		x	x
C. Stack Height Calculations	x	x	x	x	x	x	x	x	x	x	x	x
D. Support for Effects and Economic Studies	x			x	x	x			x	x		x
E. Selection of Air Quality Standards										x		x
F. Environmental Impact Statements	x	x				x	x		x	x		x
G. Attainment of Air Quality Standards												
1. Monitoring Network Design	x		x	x	x	x	x		x	x		x
2. Formulation of Control Policies		x	x	x	x	x	x	x	x	x	x	x
3. Licensing and Regulation	x		x		x	x	x				x	x
4. Supplementing Control Systems					x	x	x	x	x			x
5. Urban Alert Systems	x				x	x	x	x				x
H. Accidental Releases of Toxic Substances	x					x	x		x			x

Table 3: Examples of Literature on Model Use

Application (From Table 1)	References	Region	Country	Continent
A	Clarenburg (1970)	Rijnmond Area	Netherlands	
	Gronskei, et al. (1973)	Oslo	Norway	
	Loewenstein (1973)	Paris	France	
	Siegel (1975)			U.S.
	U.S. EPA (1973)			U.S.
B2	Slater (1974)			U.S.
B3	Bolin and Persson (1974)			Western Europe
	Boyer and Heidorn (1974)		Ontario	Canada
	Dietzer (1976)		Germany-Netherlands	Europe
	Eliasson and Saltbones (1976)		Norway	Europe
	Johnson, et al. (1976)			Central Western Europe
	Keddie, et al. (1975)	Scotland	U.K.	
	Prahm, et al. (1974)			North Atlantic
	Runca, et al. (1976)	Venice	Italy	
	Slater (1974)	New York		U.S.
B4	Bringfeldt (1974)	Stockholm	Sweden	
	Cantoni, et al. (1976)	Milan	Italy	
	Carpenter, et al. (1971)		Tennessee Valley	U.S.
	Demuth, et al. (1978)		Belgium	
	Holzworth (1972)			Contiguous U.S.
	Olsson (1976)	Stockholm	Sweden	
	Shenfeld and Boyer (1974)	Toronto	Ontario	Canada
	Turner, et al. (1976)			U.S.
	U.S. EPA (1976)			U.S.
C	Briggs (1973)		Pennsylvania,	U.S.
	Cramer (1976, 1977)		Washington, west Virginia	U.S.
	Fanaki and Turner (1976)		Ontario	Canada
	Moore (1975)		U.K.	
	Nieuwstadt, et al. (1976)	Rijnmond Area	Netherlands	
	Snyder and Lawson (1976)			U.S.
	BMI (1974)		F.R.G.	

Table 3: (continued)

Application (From Table 1)	References	Region	Country	Continent
D	Cohen, et al. (1974)	Chicago	Illinois	U.S.
E	Hogstrom (1972)		Sweden	
	Lindvall (1970)		Norway	
F	Boyer (1977)	Toronto	Ontario	Canada
	Boyer and Shenfeld (1975)	Toronto	Ontario	Canada
	Fortak (1976)	Hamburg	F.R.G.	
	Kropp (1974)		F.R.G.	
	Munn (1975)			Canada
	Nieuwstadt, et al. (1976)	Rijnmond Area	Netherlands	
	Norco, et al. (1973)	Chicago	Illinois	U.S.
	Rote, et al. (1973)			U.S.
	Sivertsen (1976)	Nedre Telemark area	Norway	
G1	Contoni, et al. (1974)	Milan	Italy	
	Lafleur (1974)		France	
	U.S. EPA (1976)			U.S.
	Cohen, et al. (1974)	Chicago	Illinois	U.S.
G2	Gustafson (1974)	Stockholm	Sweden	
	Norco and Cohen (1973)	Chicago	Illinois	U.S.
	Shenfeld and Boyer (1974)	Toronto	Ontario	Canada
	Slater (1974)	New York		U.S.
G3	MAGS (1975)	Northrhine-Westfalia	Germany	
G4	Leavitt, et al. (1971)	Tennessee Valley	Tennessee	U.S.
	Leavitt, et al. (1976)	Tennessee Valley	Tennessee	U.S.
	Norco and Raufer (1975)		Illinois	U.S.
G5	Hogstrom (1972)		Sweden	
	Niemeyer (1974)			U.S.
	Velds (1972)	Rijnmond Area	Netherlands	
H	Eidsvik (1978)		Norway	
	Humphrey (1975)			U.S.

2.3 Characterization of Existing Air Quality in Multi-Source Areas

2.3.1 Temporal and Spatial Air Quality patterns

Air quality monitoring can provide detailed information about temporal variations of concentrations at specific monitoring sites. To obtain a complete picture of both the spatial and temporal location of "hot spots" and the frequency of occurrence of high concentrations by monitoring procedures alone may be extremely costly. An excessive proportion of limited resources may be required. Modeling results may serve as valuable supplementary data. The results may be used both to interpolate between monitoring sites and to extrapolate beyond the monitoring network boundaries. Simple dispersion models can be used to assist in choosing the boundaries of air quality control areas.

2.3.2 Data Base Error Diagnosis

Several users cited the usefulness of models for diagnosing systematic errors in emissions inventory and air quality monitoring data. In any regulatory endeavor the quality of the data upon which the regulatory approach is founded is often challenged. Model results can assist in lending credence to the data base.

2.3.3 Identification of Source Contributions

In managing air quality, the initial problem is to determine the proportion of the contamination at a specific receptor that is contributed by each source or class of sources. Air quality simulation models provide the means for determining the contributions. The information is essential for selecting and designing cost-effective abatement programs.

The scale of the problem ranges from the local and rural setting to the urban, regional and international scale. On the local scale, contributions are usually unambiguous. The major problem arises over the magnitude of the contribution and the representativeness of the model and the input parameters to the circumstances. On the urban scale, where there are a large number of sources, the models require a reasonably detailed accounting routine to provide the detail that is useful for selecting control strategies. In the urban setting, it is particularly helpful to have monitored air quality data which is measured over periods which are consistent with the model application. The monitors, if properly sited, can provide information as to the "background" pollution advecting into the urban area or the contributions from unknown sources. A careful study of a consistent set of modeled and monitored data can reveal inadequate or erroneous emission data and emission characteristics of the sources. Such data can also enable judgments as to the quality of the study and confidence in the results to be assigned or estimated.

On the regional and international scales it is important to discriminate between anthropogenic and natural sources of pollutants. Air pollution control officials must know what emissions are within their power to control. An example of this problem is the increased acidity of rainfall and the dry deposition of sulfates in Scandanavia. Scientists in Europe have applied models to assess the relative contribution of anthropogenic sources to the deleterious effects of increasingly acid rain on the poorly buffered soils of northern Europe. North American scientists are also devising and applying long-range transport models to better understand the nature of similar problems.

2.3.4 Identification of Worst Case

The emissions and meteorological conditions associated with the highest air pollution concentrations are commonly referred to as "worst case conditions". While worst case can normally be associated with a relatively narrow set of conditions, it is somewhat variable and dependent on (1) the distribution and physical and operating characteristics of the sources; (2) the nature of meteorological conditions in the area (the dispersion climatology); and (3) the nature of the terrain. With appropriate models, air quality can be simulated for a wide variety of hypothetical sources and meteorological conditions to determine worst case conditions.

Pooler (1965) proposed models to estimate the worst case impact of large fossil-fueled generating plants. His hypotheses were largely confirmed by Carpenter and his colleagues at the Tennessee Valley Authority (Carpenter, et al., 1971). Turner et al. (1976), modeled the impact of 27 generating plants to determine the typical weather associated with worst case 24-hour average concentrations. He found that the nature of the worst case depended on the stack height, persistence of wind direction and the vertical temperature distribution. For short averaging times involving one or a few large sources, other authors have found that worst cases are associated with break-up of the nighttime inversions, with persistent winds, and with terrain-induced local circulations such as land-sea breezes and valley or drainage winds.

Stagnating high pressure areas (anticyclones), if they are located over areas where a large amount of pollution is emitted near the ground, are often considered worst-case events. These situations are characteristically associated with poor atmospheric disper-

sion conditions. When they have occurred over urban areas with high emissions, some of the worst air pollution episodes in history have been experienced.

Once the "worst-case" meteorological conditions have been identified, a long period of appropriate weather records can be used to estimate the frequency of occurrence of the events. Hence, models have been used to estimate the nature of worst cases, the probable maximum pollution concentrations and the frequency of occurrence of such events (Holzworth, 1972). Models are also helpful for predicting the occurrence of single air pollution episodes. However, the ability to make useful predictions depends largely on the ability to forecast local weather (U. S. EPA, 1976).

2.4 Stack Height Calculations

Calculations to determine optimum stack heights are the most universal of model applications. Indeed, where nations have no air quality standards, the use of models to select an appropriate height for a stack may be the only air pollution control function that makes use of air quality simulation models.

There are major philosophical differences among air pollution control officials as to the use of stacks to prevent violations of ambient air quality standards (Lucas, 1974; Thomas et al., 1963; U. S. EPA, 1976; U. S. Clean Air Act, 1977). Some advocate building stacks to a height that is feasible from an engineering standpoint and then controlling emissions sufficiently to avoid undesirable ground level concentrations. Others advocate controlling emissions to the extent necessary to meet acceptable ambient concentrations; stacks are used only to avoid excessive concentrations in the vicinity of the source which may result from the plume being trapped by downwash, eddies and wakes created by the source, nearby structures or terrain obstacles.

Whatever the choice of philosophies, stacks play an important role in any air quality management program. Standard methods for calculating appropriate stack heights have been established and are periodically updated by the German Union of Engineers (VDI). However, the problem is involved and easily complicated by terrain complexities or climatological conditions which were not encountered by those who evaluated the plume rise models. The problem is further complicated by the fact that different worst case meteorological conditions are associated with various stack heights (see Section 2.3.4).

2.5 Support for Effects and Economic Studies

Air quality simulation models have been used to obtain estimates of the distribution and magnitude of air pollutant concentrations. These estimates are subsequently used in studying the effects and associated costs of air pollution. The effects may concern human health, vegetation, welfare and the economy. Examples of such studies were mentioned by concerned people in Central Europe and Scandanavia. Air pollution damage to art treasures was discussed by model users, e. g. Italy. Cohen, et al. (1974) have used models for relating air pollution effects to the urban economy of Chicago.

The objective of such model applications is to estimate the exposure of sensitive receptors (people, animals, vegetation, structures) to certain harmful pollutants in a format which the epidemiologist, economist, effects engineers, etc. can relate directly to the damage being investigated. Often effects are the result of chronic exposures, although biological receptors may be vulnerable to damage only during particular phases of their life cycle. Many effects observed on both living and inanimate receptors are suspected to be related to synergisms. Problems of discriminating between anthropogenic and natural sources, discussed in an earlier section, must be considered in effects studies.

Models which relate the emissions to ambient air quality are necessary for determining the economic and energy effects associated with attaining and maintaining ambient air quality standards. Costs are generally related to the degree of emission control required to attain the air quality standards. In addition, the classic cost-effectiveness and cost-benefit relationships associated with pollution control can be evaluated. Data on cost-effectiveness and cost-benefits are useful in selecting optimum control strategies.

2.6 Selection of Air Quality Standards

Ambient air quality standards may be expressed in terms of a concentration not to be exceeded more often than some stated frequency of occurrence. By expressing standards in terms of frequency, many of the practical aspects and problems of determining whether an ambient air quality standard is in fact exceeded are implicitly recognized. Some of these problems are the uncertainties in modeling results, unrepresentativeness of monitoring sites, measurement errors, and the occurrence of rare meteorological events.

Unfortunately, the open literature contains little documentation on the use of models in choosing ambient air quality standards. Two examples, however, concern the selection of odor standards. Clarenburg (1976) described the combined use of the results of a simple area-source dispersion model and statistical analyses of citizen complaints to assist in establishing a standard for odorous emissions. The study led to a decision to alter the size of the protection zone around an industrial facility and to the necessary degree of reduction of emissions as a part of the odor abatement plan. Högstrom (1972) used dispersion modeling techniques to evaluate a method for computing odor intensities. The threshold odor data was taken from a study by Lindvall (1970) who used

data from trained subjects rather than from citizen complaints. Högstrom demonstrated that the model results enabled him to make realistic estimates of "absolute odor frequencies near point sources and that the method could be used to assess the effect of abatement strategies".

2.7 Environmental Impact Statements

The term, Environmental Impact Statement, covers a wide variety of possible air quality analyses. In fact, in Europe and North America, where the consequences of uninhibited population and industrial growth are being recognized as not uniformly advantageous, but at times deleterious on both the social and physical environment, most proposed changes in industrial or housing patterns require governmental approval. This approval is often based, in part, on the results of an estimate of impacts the completed proposal is expected to have on the physical environment. The analysis of the impact on air quality is frequently a substantial portion of the environmental impact statement. An air quality simulation model is obviously the only rational method available for estimating the change in ambient air quality. The impact statement may not be considered a normal portion of an air quality management system. But it does place the estimated air quality impact information in the public domain. Here it can be used by the public and government agencies for judging the efficacy of environmental policies and choosing the most appropriate. Some aspect of every facet of an air quality management system is to be found in environmental impact systems. No aspect is more pervasive than the models. There are many examples.

The "energy problem" which has become so prominent in the 1970's has served as an impetus for modeling to determine the impact of substituting fuels which emit relatively greater amounts of pollutants. Boyer and Shenfield (1975) and Boyer (1977) have discussed a Canadian approach to the problem. The power utility and the government's air pollution control agency applied models of increasing sophistication (and complexity) to test a broad range of possible courses of action to obtain the needed electrical energy supply with the minimum harmful effects on the air quality. In this case a subtle progression from a test of a proposal (an environmental impact statement) to the selection of a course of action developed.

Care must be taken to identify not only the direct effects, but also the secondary effects that may be stimualted by the initial action. For example, a change in a transportation system may precipitate a major change in residential, commercial and industrial development. The Verrazano Bridge which spans New York harbor changed the character of one of the New York City's boroughs almost immediately. Norco et al. (1973) present a methodology for a comprehensive assessment of the siting of a major airport facility that includes the impact of the airport and the change in land use in its vicinity. Air quality models are employed to make the assessment. A plan for St. Louis was analyzed using data from the experiences in the growth of the giant O'Hare International Airport at Chicago. Fortak (1976) developed a unique procedure to suggest an optimum design for a planned deep sea harbor and industrial area. Air quality simulation models were used to select the optimum number, distribution and height of emission points. A common model application in impact assessment deals with the air quality impact of forming pedestrian zones in inner cities approaches tended to be similar in the United States and Europe. However, naturally, the assumed driving characteristics (driving cycle) in Europe and the United Stated differed.

The impact of nuclear powered generating plants holds widespread interest on both sides of the Atlantic. Until recently most emphasis has been on the relatively small range of impacts attributed to the individual stations. However, the proliferation of nuclear reactors is causing increasing concern. Apsimon and Goddard (1976) have employed modeling procedures similar to those used to simulate the long-range transport of sulfur dioxide to consider the transport of radionuclides from the United Kingdom to the mainland of Europe. The applications are very similar, though greater attention and more detailed treatment is given to the deposition of the radioactive materials to the surface and its potential re-entrainment to the air.

Scientists from several countries cited instances where models had been used to determine the influence of government policies on emission patterns and on economic impacts of adopting ambient air quality standards.

2.8 Attainment of Ambient Air Quality Standards

The heart of air quality management is the attainment of a set of ambient air quality standards. Knowledge of the status of the air quality is essential to determine whether the standards are attained. If they are not, the status is needed to select the kind and degree of emission controls that are optimum. The following paragraphs allude to applications that may have strong regulatory aspects.

2.8.1 Monitoring Network Design

An early step in air quality management is the acquisition of appropriate ambient air quality data. This implies a monitoring or sampling network. Careful consideration of the dispersion

climate and the distribution, location and characteristics of the emitting sources is required to insure that the data collection network provides meaningful information. Air quality models are particularly useful in both the design and augmentation of such networks. If data are used in the regulatory process, it must be shown that the data are representative and relevant to the problem. In such circumstances, air quality simulation models provide a method of testing the relevance of the monitored data (see also Section 2.3.1).

Lafleur (1974) discussed the role of modeling and its constraints in monitoring design. He concluded that a simple climatological model can provide helpful information for designing networks. Olsson (1976) showed how it may be possible to use model results to reduce the number of monitoring sites to just those needed to evaluate the model calculations. A procedure for optimizing the siting of air quality monitors has been prepared (U. S. EPA, 1976); it involves the careful application of modeling results. Even in jurisdictions where the control approach emphasizes monitoring, as in the Federal Republic of Germany, several users expressed the desirability of using models in planning, developing and reviewing monitoring programs.

2.8.2 Formulation of Control Policies

When air quality standards are exceeded, some means to alleviate the situation is needed. Using sulfur dioxide as an illustration, the options may include the use of fuel with lower sulfur content, altering the distribution of sulfur dioxide emissions, installing sulfur recovery devices on emission sources, increasing the height of emissions, increasing flue gas temperatures or exit velocities, initiating intermittent control procedures and banning new sources

of sulfur dioxide in an area. Air quality simulation models provide a means for testing one or more of a set of procedures as to their efficacy in enabling the standards to be attained. Model calculations can serve as input data for further analyses of the possible social, economic and even political consequences of applying the several possible control procedures. Another procedure that may be tested with a well designed and applied model is to apply controls selectively instead of uniformly. The purpose is to find a set of controls which allows the standards to be met at lower cost than applying a uniform standard on a wide class of sources.

There have been a number of proposals to use dispersion models as a component of a larger air quality strategy system. The final component of such a system tests whether or not the air quality meets acceptable standards and evaluates the relative merits of a number of control strategies. For example, in the great petrochemical complexes of the lower Rhine, industries that desire to expand or alter their activities must estimate the expected impact on ground-level air quality. Models are used to prepare the estimates. Where concentrations are expected to be particularly high, the current and anticipated contributions of the various sources are estimated. However, in practice, a variety of constraints severely limits the number of options available. These constraints are frequently the difficulty and expense of obtaining the emission and cost of control data in the required detail.

Even though a practical application of the systems approach falls short of its theoretical potential, useful information can often be derived. Norco and Cohen (1973) used a comprehensive modeling system to assist the State of Illinois to

prepare an implementation plan for meeting ambient air quality standards for sulfur dioxide and total suspended particulate matter. They found that certain standards could not be attained in Chicago without strict controls on the myriad of residential and commercial space heating sources. Cohen, et al. (1974), used a model to demonstrate the effect of eliminating the use of coal for residential and commercial buildings. Shenfield and Boyer (1974) applied a similar modeling system called "Atmospheric Environment System" to test proposed strategies for the reduction of sulfur dioxide levels in Toronto. Slater (1974) discussed an application of the Implementation Planning Program (IPP) to the New York/New Jersey/Connecticut interstate air quality control region. The IPP has an urban dispersion model as one of its components. It was shown that a 20 % increase in the use of very low sulfur fuel would enable the national air quality standard to be attained, if the clean fuel were burned in specifically designated areas.

None of these model applications provided the only criteria or the control actions eventually taken. However, each provided bases for quantifying the nature and extent of the problems and a basis for estimating the economic costs of a solution.

Some similar experience has been developed in Europe. Gustafson (1974) described the computation of optimal air pollution strategies for Stockholm. Several European correspondents discussed courses of action which are suggested when a preliminary model analysis indicated that a desired air quality level is not attainable with available control technologies. One alternative is to extend the area, and perhaps the jurisdictions, over which an emission control standard is applied. In another example, the additonal controls and the area over which they would be required were investigated with the use of air quality simulation models.

2.8.3 Licensing and Regulation

The general instrument in the air quality strategy system of the Federal Republic of Germany is the First General Admistrative Regulation under the Federal Immissions Control Act better known as "Technical Instructions for Maintaining Air Quality". It was published in August 1974. This regulation is obligatory for those facilities which require an approval. It contains instructions for limiting the emissions (more than 200 gaseous and dust air pollutants), regulates the determination and evaluations of measured individual pollutants, and gives a calculation method to determine the minimum stack height. A special dispersion model is not yet outlined. It is only mentioned, that the relationship between emission rate, stack height and immissions can be represented mathematically by dispersion calculations.

In April 1975 a "Technical Guideline for Air Quality Maintainance in Mineral Oil Refineries and Petrochemical Facilities for the Production of Hydrocarbons" - Refinery Guideline - has been published by the Minister of Labour, Health and Social Affairs of the Federal State of Northrhine-Westfalia.

This guideline gives final directions on the technical requirements for reducing emissions, instructions for the measurement of the existing impact on ground-level air quality, air quality standards, and a detail description of a dispersion model including all boundary conditions, how to combine the calculated and measured immissions and how to compare this combined data with air quality standards. Besides the regulations concerning refineries and other hydrocarbon facilities the Gaussian dispersion model is of general interest.

For nearly all approval processes it is obligatory to calculate the expected air pollution impact by this guideline.

For one stack the number of the receptor points respectively the dimension of the area to be investigated is regulated in the "Technical Instructions" and depends on the expected stack height. For a height up to 200 m for instance the area has a size of 8 km x 8 km with a distance of the receptor points of 1 km each.

In those cases where the "Technical Instruction of Maintaining Air Purity" (under Federal Authority) gives no special advices the "Refinery Guideline" has to be applied in the Federal State Northrhine-Westfalia. Many other Federal States join up with the dispersion model of this guideline.

Elements of the model are:

a) Basic Equation

b) Plume Rise Formula (Moses and Carson)

c) Stability Classes (after Turner)

d) Dispersion Coefficients for three "effective source heights" (Singer-Smith/Mc Elroy - Pooler, modified by Fortak)

e) Wind Speed Profile

A variation of the fixed values (e. g. dispersion categories by Klug) is only permitted by the agreement of the Minister of Labour, Health and Social affairs of Northrhine-Westfalia.

These strong uniform procedure is necessary to ensure that all evaluations of the application for granting licences follow the same pattern. This fact is of special importance in the industrial area of Northrhine-Westfalia where the air quality standards in some cases are nearly attained. The inaccuracies of the calculation method and of the dispersion situations are taken into account. A safety factor of 1.5 is to be used. That means the calculated average concentration for one year at one grid point has to be multiplied by 1.5.

Statistics for the dispersion categories are available in the Federal Republic for about 70 locations (published by the German Weather Service).

Since April 1975 the model has been practised in more than 200 approval processes. Mostly more than 10 calculations were necessary, to optimise all alternatives of emissions.

2.8.4 Supplementary Control Systems

Supplementary control systems are based, in theory, on the air quality management concept in its purest sense; namely, that emissions can be varied spatially and temporally in such a manner that ambient air quality standards, goals or objectives are always achieved. Usually emissions are reduced during periods of adverse atmospheric dispersion conditions to avoid exceeding an ambient air quality standard. These programs are most effective when used in areas where the short-term (a few minutes to 24 hours) standards rather than long-term (annual) standards are threatened and where most of the pollutants are emitted by a few dominant sources which can change emission rates quickly, easily and economically.

A properly designed program consists of several components. An emission component provides continuous data on the current and scheduled emission rate for all sources. A meteorology component provides information on the past, current and expected status of the transport and dispersion characteristics of the atmosphere. An air quality component provides the past and current status of ambient air quality. An operating model component integrates the information and provides estimates of the quality of the ambient air for the next few hours or one or two days. The components may be combined and applied in a variety of ways to meet the needs of the particular location, jurisdiction or operating characteristics of the emission sources.

Because each source or group of sources will be characterized by a unique combination of factors, the development of each program tends to be a case-by-case undertaking. For example, the critical meteorological conditions which are conducive to violations of an ambient air quality goal are determined by the physical characteristics and operating methods of the emission sources. Similarly, the details of the model, are often determined only after a careful site evaluation and comprehensive study of the local emissions, meteorology and air quality. The models may then provide information upon which the optimum control actions may be selected. Further, they may be used to evaluate the effectiveness of each stage of development of hypothetical pollution episodes. This aspect of air quality management has been discussed extensively in the literature. Often under a variety of titles such as "intermittent control systems", "emission limitation programs", "closed loop systems", "open loop systems", "meteorological control systems" as well as "supplementary control systems". (Roberts, et al., 1970; Mahoney, 1971; Leavitt, et al., 1971; Wolsko, et al., 1973; Wangler and Rossin, 1973; Bankoff and Hanzevack, 1975; Niemeyer, 1974; Leavitt, et al., 1976).

2.8.5 Urban Alert Systems

Episodes of high air pollution generally occur during unfavorable meteorological conditions, such as persistent stagnant air conditions. This type of air pollution problem may require an alert system or an episode control plan. Such urban alert systems generally consider three types of problems (OECD, 1974):

(1) The build-up of unacceptably high concentrations of primary pollutants such as sulphur oxides and particulate matter, nitrogen oxides and carbon monoxide, which may cause adverse health effects.

(2) The build-up of secondary pollutants, e. g. photochemical oxidants which may be a source of nuisance and cause adverse effects both in the region itself and at some distance from the primary pollutant emission sources.

(3) General public complaint about nuisance, particularly with respect to odor (NATO/CCMS, 1972; Hogstrom, 1972).

The information requirements in episode planning have been summarized by Niemeyer (1974). Included in an operational alert system is the capability to predict, detect and react to dangerous air pollution concentrations, acting within a time scale of hours or fractions of an hour. The quick-reaction system envisioned depends on high speed data-processing equipment and refined mathematical models that permit prediction of hazardous air pollution concentrations. Furthermore, the system depends on a widespread continuous monitoring network. Continuous monitoring of sources through permanent stack monitors that telemeter measurements to a central facility also are useful.

Equally important, a quick-reaction system must have a fully developed command and control structure. In most areas that utilize alert systems, the action to reduce emissions is initiated under given criteria. The criteria should be based on measurements of air pollution concentrations and their trend. In some areas, for example in Japan, the criteria for emission reduction also include a forecast of dispersion conditions. In this case the forecasting procedure is formalized in order to reduce subjective judgment to a minimum when calling an alert. In such a system of criteria, secondary pollutants cause special problems since there may be a considerable delay between the emission of primary pollutants and the episode of high secondary pollution.

Limited experience is available, where validated air quality models have been used in urban alert systems. Wrangler and Rossin (1973) quantify the effectiveness of a hypothetical control strategy by using an air quality model. In the Rijnmond area of Rotterdam, an extensive on-line air monitoring network continuously reports the present levels of air pollutants. Air quality models have been applied to some of the episodes (Velds, 1972).

In the United States, the National Weather Service has taken action to develop a forecasting capability (Kirschner, 1971). Alert systems are required to be included in the state implementation plans in polluted areas. Forecasting of stagnation takes place on a national basis in the United States, and this information is used by local control agencies, who evaluate its significance for local air quality. Urban alert systems have furthermore been operating in metropolitan areas such as Toronto, Montreal, Milan and Frankfurt. A summary re-

port on the use of air pollution alert system was prepard by the OECD (1975). The report summarizes some of the results as follows:

- Positive results have been observed with the operation of alert systems in the participating countries, despite comparatively limited experience. The real time surveillance and control techniques of the alert system have additionally served several functions within the context of ongoing air management programs, including the provision of historical air quality or meteorological data. This has, in turn, provided a basis for defining an air pollution problem and developing strategies for abatement. For several countries, particularly the Netherlands and Japan, advanced monitoring systems permit early detection of accumulated pollutants.

- Surveillance activities have also been successful in keeping the public appraised of air quality levels. In some regions, Ontario, Canada, for example, there has been public demand for extension of alert systems to other communities as mass media and various interested groups have reacted favorably to the system.

- With alert systems depending on voluntary cooperation procedures, several countries report good relations with industry. For example, in the Rijnmond area of the Netherlands, where in recent years there has been a significant decrease in nuisance from odorous compounds, industries have made structural improvements, in addition to cooperation during alert periods, in an effort to control air pollution.

2.9 Accidental Releases of Toxic Substances

Most pollution control activities of both government agencies and industrial facilities have contingency plans to deal with accidental or inadvertent releases of toxic or hazardous pollutants. An air quality model for estimating the area of potential threat and the probable magnitude of the concentrations is often an integral part of the contingency plans. The use of models for real-time warning systems to aid in the protection and possible evacuation of the population exposed to the contamination was discussed by many of the people contacted.

It is ironic that although emergency plans are one of the most widely cited uses for models, the use of models for this purpose are not widely discussed in the open literature. Nevertheless, there are numerous examples of internal reports, accounts of dicussions at symposia and workshops, and instruction handbooks on the subject (Dumbauld, et al., 1970; Humphrey, 1975; Petersen, 1976; Eidsvik, 1978). The models are frequently presented in the form of nomograms and are addressed toward a "worst-credible" situation. Of necessity, they are usually extremely simplified to facilitate their immediate application by the individuals responsible for dealing with the emergency.

3. PRESENT AND FUTURE NEEDS

3.1 General

Air quality models attempt to represent turbulent dispersion processes of the atmosphere. Because many of the processes are incompletely understood and because it is often not feasible to quantify adequately those processes that are understood, the models cannot be expected to always meet the restrictive accuracy limits that are often demanded. It is essential for those who make the air pollution control policy decisions, that are based in part on results of models, to appreciate a model's strengths and weaknesses. Whenever possible, those who develop and apply the models should provide control officials with confidence estimates in their results rather than qualifications and caveats. It is incumbent upon both parties to take those actions which enhance communications on this matter. Present and future needs to improve the applicability of Gaussian models were discussed with NATO users. Enumerating them may assist in furthering understanding of modeling capability. The needs that follow are of a pragmatic, not necessarily scientific nature.

3.2 Model Documentation

A pressing current need of model users is a comprehensive manual for each operational model. The manual should provide the purpose of the model, specify its intended applications and note its limitations.

The document should descirbe mathematical and theoretical bases for the model and state the assumptions involved. It should summarize previous applications and the verification or vali-

dation studies performed. It should specify the computer language in which the program is available and provide a computer program listing in at least one commonly used source code. It should discuss the input and user resources that are required to implement the model properly. Finally, the manual should include an example model application which may serve as a test case for evaluating the model's operation on the user's computing facility (U. S. EPA, 1977).

3.3 Guidance in the Use and Selection of Models

One of the major purposes of model documentation is to provide a basis for the user to decide which model, if any, is appropriate for his particular application. At present, the choice of the model is frequently determined by the form in which the input data are available, the characteristics of the available computing equipment and the experience of the technical staff of the user agency.

A user-oriented workbook that provides assistance in comparing modeling approaches from a technical standpoint has been developed by Smith, et al. (1978). The procedure, which is reasonably objective, requires the user to express the specific modeling application in terms of standard modeling terminology. It then assists the user in identifying the modeling features that are most and least important for the particular task. The procedure also provides a framework, based on how alternative models treat each of the important modeling features, for comparing the models and choosing the one which best meets the need. The entire system is limited by the state-of-the-art of modeling and the adequacy of the documentation of the models. The system does provide a rational mechanism by which persons with diverse but technical backgrounds can reach agreement on the most appropriate models.

The diversity of topography and climate, and variations in source configurations and operating characteristics rule against a routine, standard analysis. No one model is capable of representing all meteorological circumstances associated with serious air pollution; situations are often too complex for simple mathematical treatment. Any modeling effort should involve (1) competent individuals with a broad range of experience and knowledge in air pollution meteorology and (2) specialists in emission characteristics and data processing. The judgment of well-trained professional analysts is essential.

3.4 Model Validation and Calibration

As pointed out in Section 1.2, policy makers and planners are reticent to base emission control decisions that have great economic and social implications on results of analytical procedures containing assumptions that are not universally accepted. There is a clear need for specific and uniform validation procedures. Since comprehensive procedures are not available, judgments on the usefulness of models are developed through a validation process (Johnson, 1972). The process consists of a series of analytical steps: (1) comparing estimated and measured concentrations; (2) determining the cause of discrepancies; (3) correcting input data; (4) modifying the model (if necessary) to improve the mathematical representation of physical reality; and (5) documenting the accuracy of the estimates (U. S. EPA, 1978).

Calibration of models is the process of identifying systematic errors and applying a correction factor. In many cases the process involves applying a statistical technique to adjust model estimates for increasing agreement with measured data. Long-term (seasonal or yearly averaging times), multi-source models

are often calibrated. Calibration of short-term models is not widely practiced because of the inability to estimate a concentration at an exact location for a specific short time-period (1 to 24-hours).

A major limitation in the greater use of models is the difficulty of placing firm error bands and limits of uncertainty on the model results. Uniform, objective and quantifiable validation procedures are needed. Standards of performance for models, which might be expressed in terms of limits of uncertainty, would be expected to follow.

3.5 Common User Problems

Several common problems were evident from dicussions with model users throughout the NATO countries.

First, many industrial cities are located on coastlines. Investigators have found that the standard stability classification procedures used for the Gaussian plume model is not completely applicable. Also the available meteorological data are often collected some distance inland and may not represent dispersion conditions on the coast. This is largely a problem of obtaining representative input data. Collecting test data in the area of interest for a short period to compare with the routinely available data may provide a solution. Field tests to quantify dispersion rates along shorelines are also necessary. Plans for experiments of this nature in both Europe and North America were alluded to.

Second, what procedures should be followed to modify the original Pasquill stability classifications to account for local conditions? There are two immediate courses of action, neither of which may be completely satisfactory. For the immediate response, obtain the services of a dispersion meteorologist who has had useful experience in similar locales. For the longer term, a field study is appropriate. It is likely the only satisfactory solution if the terrain factors are truly unique.

Third, most users expressed concern that model treatments of area sources tended to overestimate observed concentrations. Some suggested that a more sophisticated and detailed emission inventory would alleviate some of the problems.

Fourth, the estimation of air quality during calm and near calm conditions was considered by some users to be a major problem. Citing the Frankfurt data base as an example, the Gaussian plume model was applicable to only 70 % of the meteorological conditions. Experience suggests that the treatment of calms is not critical for computing long-term concentrations. No satisfactory method exists for using the Gaussian approach to estimate short-term concentrations in near-calm or calm conditions was suggested.

4. CONCLUSIONS AND RECOMMENDATIONS

The chapter 1.3 of this report contains the major conclusions to the OECD Report submitted by Mahoney in 1970. Where do we stand at this point in air quality modeling history relative to those conclusions?

First, in the past several years, model applications have expanded in both variety and extent in all of the NATO countries.

Second, a shift from academic and limited regulatory uses to more extensive air quality management-related uses is taking place in most countries employing models.

Third, a greater emphasis is being placed upon the needs of model users and the special requirements of air quality managers. This emphasis is providing incentives and support
(1) for improved guidance on the application of models;
(2) for better and more complete model validation;
(3) for standards of performance for models; and
(4) for treatment of specific problems not adequately addressed previously.

Fourth, the current generation of model developers in most NATO countries are actively pursuing the problems of mesoscale and long-range transport as well as the chemical and physical transformation of pollutants. Some of these mesoscale and long-range models are at a stage of development and evaluation that justifies their use for advisory purposes. Also, the latest advances in photochemical models combined with smog chamber experiments show promise of yielding useful analytical procedures for assessing the impact of precursor emissions (Dimitriades, 1977; Dodge, 1977).

Fifth, model accuracy has shown only modest improvement. This may be due to the absence of significant advances in model validation procedures and data base development. However, substantial experience has been gained in the application of models under an extensive range of conditions. Investigators have achieved improved results through the modification of modeling parameters.

Finally, substantial progress in air quality simulation modeling awaits a better understanding of how the proposed treatments of all processes governing the transport and fate of pollutants affect the performance of models. As an example, loss processes are not adequately accounted for in current state-of-the-art models. There is not a general means of bringing the analyses of the processes together in such a manner that an a priori level of confidence can be assigned to any particular model estimation. Hence, Mahoney's caution that "undertaking elaborations of existing models should be subject to the most critical scrutiny" remains valid.

Progress has been made in single source modeling. Possible ground-level maximum concentrations can now be estimated for areas of simple terrain with reasonable accuracy. However, the status of estimating concentration frequency distributions is not clear. The ability to predict concentrations in complex terrain remains uncertain. Evidence is accumulating that the original dispersion parameters recommended by Pasquill and Gifford may not be applicable to point sources in many circumstances to which they are currently being applied. Experience in a number of urban areas in the NATO countries also indicates that parameter choices for urban models require extensive review at this time.

With the expanding role of air quality standards in the NATO community, there is a growing need for greater uniformity in models for regulatory purposes. The process of standardization, if it occurs at all, should utilize the collective experiences and expertise of the model developers, testers, evaluators and model users throughout the NATO community and should be based upon model performance criteria yet to be defined.

Finally, the strong spirit of cooperation that has been evident at technical meetings sponsored by the NATO/CCMS modeling panel can serve as the basis for considerable advances in the area of model validation and application and, therefore, should be encouraged. Not only could data bases be packaged in uniform formats, and exchanged, but experience in the application of models under a variety of meteorological and geographical conditions could also be exchanged for the mutual benefit of the entire model user community.

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ANNEX II

NATO/CCMS Documents on the First Air Pollution Pilot Study (available at: NATO/Committee on the Challenges of Modern Society, NATO Headquarters, Brussels, Belgium)

AIR POLLUTION (No. 5)

Proceedings of the 2nd Meeting of the Expert Panel on Air Pollution Modeling, (26 - 27 July 1971, Paris, France). Out of stock

AIR POLLUTION (No. 6)

Guidelines to Assessment of Air Quality (Revised)

APPENDIX A	Assessment of Air Quality in Ankara (February 1973)
APPENDIX B	Assessment of Air Quality in St. Louis (February 1973)
APPENDIX C	Assessment of Air Quality in Frankfurt (June 1974)
APPENDIX D	Assessment of Air Quality in Oslo (February 1973)
APPENDIX E	Assessment of Air Quality in the South Holland Region (December 1973)

AIR POLLUTION (No. 7)

Quality Criteria for Sulphur Oxides (November 1971). Out of stock

AIR POLLUTION (No. 8)

Air Quality Criteria for Particulate Matter (November 1971). Out of stock

AIR POLLUTION (No. 10)

Air Quality Criteria for Carbon Monoxide (June 1972)

AIR POLLUTION (No. 12)

Control Techniques for Sulphur Oxide Air Pollutants (October 1973)

AIR POLLUTION (No. 13)

Control Techniques for Particulate Air Pollutants (October 1973)

AIR POLLUTION (No. 14)

Proceedings of the 3rd Meeting of the Expert Panel on Air Pollution Modeling (2 - 3 October, 1972, Paris)

AIR POLLUTION (No. 15)

Air Quality Criteria for Nitrogen Oxides (June 1973)

AIR POLLUTION (No. 18)

Control Techniques for Carbon Monoxide Emissions from Stationary Sources (October 1973)

AIR POLLUTION (No. 19)

Control Techniques for Hydrocarbon and Organic Solvent Emissions from Stationary Sources (October 1973)

AIR POLLUTION (No. 20)

Control Techniques for Nitrogen Oxide Emissions from Stationary Sources (October 1973)

AIR POLLUTION (No. 29)

Air Quality Criteria for Photochemical Oxidants and Related Hydrocarbons (February 1974)

AIR POLLUTION (No. 30)

Proceedings of the 4th Meeting of the Expert Panel on Air Pollution Modeling, (28 - 30 May 1973, Oberursel, Germany)

AIR POLLUTION (No. 33)

Final Report (May 1974)

AIR POLLUTION (No. 35)

Proceedings of the 5th Meeting of the Expert Panel on Air Pollution Modeling (4 - 6 June 1974, Roskilde, Denmark)

AIR POLLUTION (No. 41)

First Follow-up Report (December 1975)

AIR POLLUTION (No. 50)

Second Follow-up Report (December 1976)

AIR POLLUTION (No. 67)

Third Follow-up Report (November 1977)

AIR POLLUTION (No. 96)

Fourth Follow-up Report (October 1978)

AIR POLLUTION (No. 6, Appendix C revised)

Assessment of Air Quality in Frankfurt (December 1977)

ANNEX III

NATO/CCMS Documents on the Pilot Study on Air Pollution Assessment Methodology and Modeling
(available at: NATO/Committee on the Challenges of Modern Society, NATO Headquarters, Brussels, Belgium)

Air Pollution (No. 42)

Proceedings of the 6th International Technical Meeting on Air Pollution Modeling and its Application
(24 - 26 September 1975, Frankfurt/Main, Germany)

Air Pollution (No. 51)

Proceedings of the 7th International Technical Meeting on Air Pollution Modeling and its Application
(7 - 10 September 1976, Airlie House, USA)

Air Pollution (No. 70)

Bibliography on Grey Literature on Air Quality Modeling, Part I (Applied Models) (October 1977)

Air Pollution (No. 71)

Air Quality Management Systems (AQMS) (October 1977)

Air Pollution (No. 88)

Bibliography on Grey Literature on Air Quality Modeling, Part II (New Modeling Techniques) (October 1978)

Air Pollution (No. 89)

Glossary of Terms Generally Used in Air Pollution Assessment Methodology and Modeling (October 1978)

Air Pollution (No. 80)

Proceedings of the 8th International Technical Meeting on Air Pollution Modeling and its Application
(20 - 23 September 1977, Louvain-la-Neuve, Belgium)

Air Pollution (No. 99)

Introduction to Air Quality Modeling (October 1978)

Air Pollution (No. 100)

Air Pollution Emissions Projecting (October 1978)

Air Pollution (No. 101)

Uses and Needs for Air Quality Modeling (May 1979)

Air Pollution (No. 102)

Fundamentals for the Application of a Gaussian Plume Model
(April 1979)

Air Pollution (No. 104)

Air Pollution Emissions Inventory Systems
(October 1978/July 1979)

APPENDIX A: Emissions Inventory in Belgium
APPENDIX B: Emissions Inventory in Canada
APPENDIX C: Emissions Inventory in Germany, Federal Republic of
APPENDIX D: Emissions Inventory in The Netherlands
APPENDIX E: Emissions Inventory in Norway
APPENDIX F: Emissions Inventory in the United States of America

Air Pollution (No. 106)

Practical Demonstration of Multiple Source Urban Air Quality Modeling (Gaussian Plume) (August 1979)

Air Pollution (No. 71, Revised)

Air Quality Management Systems (AQMS) (April 1979)

Air Pollution (No. 105)

FINAL REPORT (October 1979)

Air Pollution (No. 103)

Proceedings of the 9th International Technical Meeting on Air Pollution Modeling and its Application
(28 - 31 August, 1978, Toronto, Canada)

Air Pollution (No. 108)

Proceedings of the 10th International Technical Meeting on Air Pollution Modeling and its Application
(23 - 26 October, 1979, Roma, Italy)